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COMMENTS

Comment on the Observation of a Moving Magnetic Monopole

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It is determined that if the recent observation of a cosmic-ray track is accepted as produced by a magnetic monopole then the magnetic charge must correspond to a south-seeking pole for a monopole mass less than 6.6×10^3 GeV/c^2. In addition, the pole could not have been produced by a primary cosmic ray in the upper atmosphere.

Recently, evidence has been submitted for the observation of a moving magnetic monopole.[1] If the event was due to a monopole then it was moving rather slowly, $V_{\rm lab} \simeq 0.5c$, and was very heavy, $M > 200$ GeV/c^2. The low velocity but constant ionization rate of the observed particle was primary to the interpretation of the event as a monopole. However, at first glance, the low velocity appears inconsistent with the strong interaction of the particle with Earth's magnetic field[2] and the relativistic energies necessary to have created such a massive particle.[3] Under the assumption that the event was due to a monopole, it will be shown that (1) from kinematics alone the event could not have been produced in the upper atmosphere by a primary cosmic ray and (2) the magnetic charge must have been a south-seeking pole decelerated from relativistic velocity by the magnetic field of Earth if the monopole mass was less than 6.6×10^3 GeV/c^2.

In the first place monopoles should be produced in pairs.[4] Thus the energy in the zero-momentum frame is greater than two monopole masses plus the energy to separate them to infinity (~ 39 GeV for a particle radius of 1 fm) minus the masses of the incident particles. With disregard of a

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coherent mechanism where all or part of a nuclear mass could be converted into a monopole and with use of only high-energy nucleon-nucleon collisions, the lab energy, $E_{\rm lab}$, in the ultrarelativistic limit is

$$E_{\rm lab} \simeq E_{\rm c.m.}{}^2/2m_p, \qquad (1)$$

where $E_{\rm c.m.}$ is the energy in the zero-momentum frame. This results in the zero-momentum-frame γ^* as

$$\gamma^* = E_{\rm c.m.}/2m_p, \qquad (2)$$

where $\gamma^* = [1/(1-\beta^{*2})]^{1/2}$ and $\beta^* = v^*/c$. In this equation v^* is the velocity in the zero-momentum frame and c is the velocity of light. For a monopole mass $M > 200m_p$, then $\gamma^* > 200$ and $\beta^* \simeq 1$. The lab momentum is bounded by the momentum transformation of the forward- and backward-recoil particles in the zero-momentum frame. This gives

$$P_{\rm lab} \simeq \frac{\gamma^* M}{(1 \mp \beta_{\rm c.m.})^{1/2}}(1 \pm \beta_{\rm c.m.})^{1/2} \simeq \frac{M^2/m_p}{1 \mp \beta_{\rm c.m.}}, \qquad (3)$$

where $\beta_{\rm c.m.}$ is the monopole velocity in units of c in the zero-momentum system. For the values of $M > 200$ GeV/c^2 and $\gamma^* > 200$ then

$$P_{\rm lab} > (200)^2/2 \text{ GeV}/c, \qquad (4)$$

and the velocity of the monopole is ultrarelativistic.

If produced in the upper atmosphere then the monopole must be drastically decelerated to reach the observed velocity of $0.5c$. Obviously this cannot happen for a north-seeking pole falling in Earth's northern magnetic hemisphere, and even the strong repulsion of a south-seeking pole cannot decrease the velocity by the required factor. These statements are verified by numerical integration of the relativistic force equation,

$$d\vec{p}/dt = ge\vec{B}, \qquad (5)$$

backward, given the observed monopole velocity, mass, and position. In the solution of this equation a perfect dipole field for Earth was assumed and an initial velocity lying in a plane of field lines. Though the magnetic field of Earth is dis-

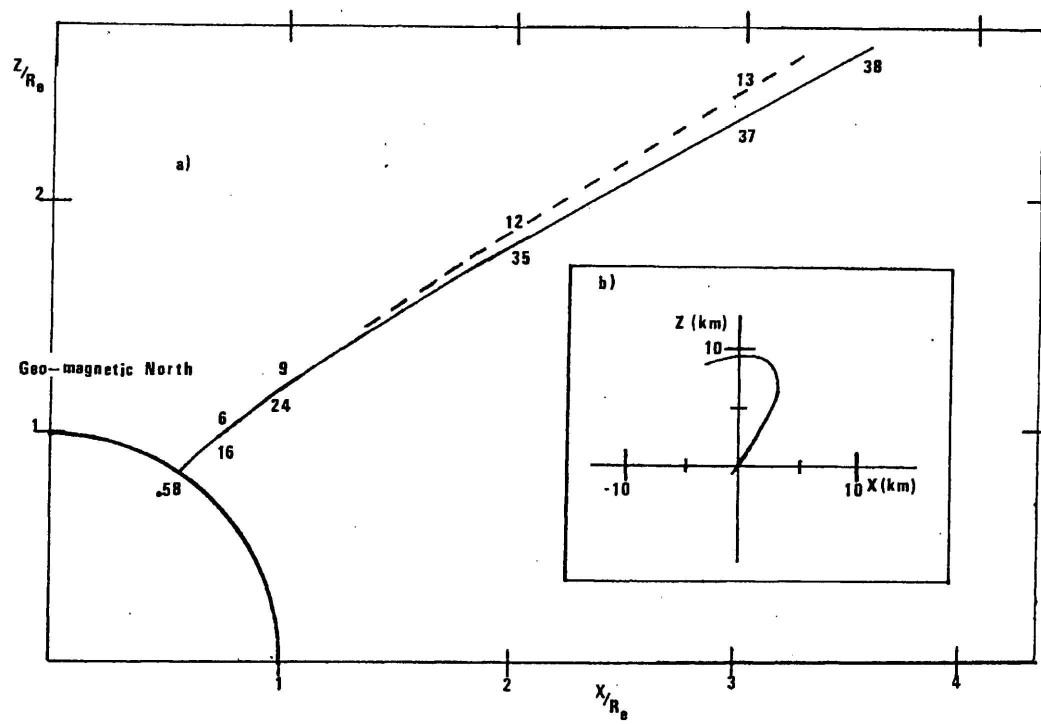

FIG. 1. (a) Reconstructed trajectories of a $M=200$-GeV/c^2 (solid curve) and $M=600$-GeV/c^2 (dashed curve) south-seeking monopole in the magnetic field of Earth. Values of momentum in units of the monopole mass at various points on the trajectory are shown. The upper number corresponds to $M=600$ GeV/c^2 and the lower number to $M=200$ GeV/c^2. Distances are measured in units of Earth radii. (b) Trajectory of a north-seeking pole. Distances are in kilometers from the point of detection.

torted by the solar wind, the general conclusions reached here are not expected to change. As can be seen from Fig. 1(a) a north-seeking pole of $M=200m_p$ moves upward above the detector about 9 km and then is accelerated downward striking Earth. A south-seeking pole is rapidly accelerated to a terminal velocity and its trajectory remains relatively unaffected after several Earth radii. This is because of the $(1/r)^3$ decrease in field strength and the high momentum of the particle. Figure 1(b) shows trajectories for monopole masses of 200 and 600 GeV/c^2 at vertical incidence. Incidence $\pm 20°$ about the vertical does not change the calculated trajectory appreciably. The south-seeking pole does not reach sufficient energy anywhere along its trajectory to have been created by a nucleon-nucleon collision in the atmosphere of Earth. In addition, with use of the observed initial conditions and even disregard of ionization loss in the atmosphere, neither a south-seeking pole of mass $M=200$ or 600 GeV/c^2 would strike Earth. A $M=200$-GeV/c^2 south pole would essentially follow the trajectory of Fig. 1(b) with $x \to -x$ and $z \to -z$.

There is a question as to whether this south-seeking–pole trajectory is bound (i.e., whether or not the trajectory will eventually bend back to Earth). It can be shown that given the last determined position and velocity from Fig. 1(a) the remaining field is not sufficient to bend the particle to a trajectory parallel to the x axis. Thus the trajectory is unbound. It can also be shown that the momentum received must be less than $\sim 45Mc$, which is the momentum obtained by moving a pole along the z axis to infinity.

If the monopole were extremely massive then it is possible for a north-seeking pole to be relatively unaffected by the magnetic field of Earth. Equation (4) may be integrated to show that for vertical incidence the minimum monopole mass (zero initial velocity) is about 6.6×10^3 GeV/c^2 to attain a velocity of $0.5c$ at the surface of Earth. Thus in all likelihood if the observed track was due to a monopole it was a south-seeking pole and came from outside the magnetic field of Earth.

There have been a number of searches for thermalized monopoles on the surface of Earth[5] and in moon rock.[6] If the rather large flux of monopoles quoted in Ref. 1 is taken at face value it presents some problems in interpreting the negative results of these experiments. A flux of 10^{-13} cm^{-2} sec^{-1} sr^{-1} based on one event was assigned.[1] This is 4×10^5 greater than the flux limit determined in Ref. 5 for monopoles in the cosmic-ray flux with energies less than 10^{19} eV.

Finally to distinguish between heavy-ion and monopole tracks by use of ionization it would appear that future searches for moving monopoles should concentrate at high latitudes to look for decelerated, low-velocity, constantly ionizing events. The author gratefully acknowledges stimulating conversations with W. Z. Osborne, L. S. Pinsky, J. C. Allred, and B. W. Mayes.

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